Examining the role of biomass energy for sustainable environment in African countries

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ABSTRACT

Purpose-This paper investigates the influences of biomass energy use, fossil fuel, income, trade openness, and population growth on carbon dioxide ($C0_2$) emission in African countries over the 1980-2014 period.

Design/methodology/approach- The study employs pool mean group (PMG), mean group (MG), and dynamic fixed effect (DFE) estimators that resolve the issue of heterogeneity bias. In addition, it employs weighted fully modified ordinary least squares, and weighted dynamic ordinary least squares to validate the robustness of PMG, MG, and DFE estimates.

Findings- The results from each of these estimators complement one another and both suggest that the relation of fossil fuel use and population growth with CO_2 emission is positively significant. Conversely, we find that trade openness and biomass energy use exert significant negative impact on carbon emission. Additionally, the dampening effect of biomass energy utilization on CO_2 emission helps to validate Environmental Kuznets Curve (EKC) hypothesis for those countries.

Originality/value- The role of biomass in determining environmental quality has been investigated by studies for a few developed economies and developing countries without reaching consensus in terms of their findings. As indicated by the literature, such study is wanting in African countries, and

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this motivates the present study. More so, with focus on the role of biomass in CO_2 emission, this study first considers sixteen countries from all the regions on the African continent. The findings of this study will assist policy makers in making useful environmental and sustainable energy policy that can be embraced as regional policy.

Keywords: CO_2 emissions, Biomass, Fossil fuel, trade openness, GDP per capita, Africa

1. **Introduction**

The challenges of global warming and rampant climate change have continued to attract the attentions of policy making authorities, environmentalists, and society at large. More attention is needed as the global energy use and carbon dioxide (CO_2) emissions rose simultaneously by 2.9% and 2.0% respectively in recent time, exceeding their growth rates recorded each year since 2010 to 2011 (BP, 2019). Carbon emissions through increase in greenhouse (GH) gases, causes the global temperature to rise, earth's surface to warm, and as a result changes the climate. Consequently, there would be drought, low agricultural yield (Yahaya et al., 2020), poor state of human health and people's well-being (Danish and Wang, 2019; Adeel-Farooq et al., 2021). Limiting warming to an estimate of about 1.5°C above pre-industrial levels would be desirable and require universal implementation of cross-sectoral climate mitigation, combined with sustainable development (IPCC, 2018). Therefore, understanding the causes of global warming and solutions to its challenges will be helpful to transition to a low carbon, and toward attaining the Sustainable Development Goals (SDG).

As earlier shown in the literature, one of the major causative factors of gaseous emissions is economic growth (Beckerman, 1992; Grossman and Krueger, 1991, 1995; Shafik, 1994). Due to its substantial, contribution to the gaseous emissions, economic growth is often used to test the Environmental Kuznets Curve (EKC) hypothesis by examining its relationship with environmental pollution. The hypothesis connotes that a threshold exists for a worsening environment as the level of per capita income continues to increase. This threshold is attained when the average income gets to a particular level and shows an inverted U-shaped relation with environmental degradation. The path-breaking empirical study on EKC was credited to Grossman and Krueger (1995) who found an U-

shaped EKC, by using a quadratic EKC in levels. Subsequently, some earlier studies such as Beckerman (1992), Shafik and Bandyopadhyay (1992), Panayotou (1993), and Shafik, (1994) have also found an inverted U-shaped EKC, which suggested a non-linear relation of per capita income with pollution. However, studies such as Selden and Song (1994), Stern et al. (1996), and Saboori et al. (2012) failed to validate EKC hypothesis, though concluded that economic growth hurt the quality of environment. Due to lack of unanimous conclusion on the outcomes of EKC, the hypothesis continues to receive researchers' attention till today.

In addition, the use of energy generated from fossil fuels has played a vital role in GHGs emissions (Bilgili, 2012; Katircioglu, 2015; Yahaya, et al., 2020). Global warming and climate change according to IPCC are results of CO_2 emissions from the fossil fuels burnt. Effort to avert the impacts across ecosystems and economies requires that global warming be stabilized at 1.5°C by cutting fossil fuel use (IPCC, 2018). The priority to achieve this goal has motivated the pursuit of alternative energy sources and environmental sharp restraints on fossil fuel energy use, compelling industries to consider renewable fuels. The use of energy from its clean source is viewed an effective tool of solving the current environmental problems (Owusu and Asumadu-Sarkodie, 2016), and the use of such clean energy has been increasing in recent time (Danish and Ulucak 2020). Biomass as source of renewable energy (known as bioenergy) has the potential of easing the concerns of GH gases emissions and global climate warming and could serve as substitute to the fossil fuel, a non-renewable energy source. As noted by Shahbaz et al. (2021), the substitute energy sources should be recognized as a policy tool to make energy clean and cost-effective and thus, as a tool to ascertain energy security.

Biomass constitutes wood made from forest and agro-industrial plantations, or non-wood generated from plant stems, leaves, crop remains, etc (Bildirici & Ozaksoy, 2018; Schuck, 2006). In its various forms, biomass has been used for production of fuel, heat and electricity generation, Further; biomass wood has been used directly for cooking purpose too. Conventionally, the use of

biomass energy is based on the belief that carbon emissions from the burning of biomass have neutral or zero global warming effects (Liu et al., 2020) as such emissions are considered being offset in the process of plants' photosynthesis (Darda et al., 2019). Hence, bioenergy sourced from biomass may help to resolve GH effect by curbing carbon emissions efficiently.

Incidentally, most developing nations employ biomass energy to satisfy around 35 percent of their domestic energy needs (Sarkodie et al., 2019). In this context, African countries are not left out. For example, the countries are very rich in biomass and a sizeable percentage of Africans generates more than 80% of fuel from biomass to meet their cooking needs (UNDP, 2009). Besides, African household who makes up the low-income bracket obtains around 80 to 90 percent of their needed energy from biomass source (Iiyama et al., 2014). The use of this type of energy is likely to influence the level of gaseous emission in those countries.

A possible question is, can biomass energy use enhance environmental quality by lessening CO_2 emissions? A survey of literature suggests that the question has been answered for a few developed economies (see Baležentis et al., 2019; Bilgili, 2012; Bilgili et al., 2016; Bilgili et al., 2017; Sarkodie et al., 2019; Shahbaz et al., 2017) and developing countries (see Adewuyi and Awodumi 2017; Carvalhoa et al., 2019; Danish and Ulucak, 2020; Katircioglu, 2015; Shahbaz et al., 2019; Wang et al., 2020). These studies found that biomass energy helped to mitigate pollution. However, Shahbaz et al. (2018) for developed economies and Adewuyi and Awodumi 2017, Solarin et al. (2018) and Mahmood et al. (2019) for some developing countries found that biomass energy use degraded the quality of environment. As observed by Adewuyi and Awodumi (2017), and Danish and Wang (2019), little is known in the literature concerning the relation of biomass energy use with pollution, as no consensus is reached by those few studies in terms of their findings. Thus, there is need for more studies to deeply understand how biomass energy impacts carbon emission. More importantly, the literature indicates that such study is indispensable in the context of African countries.

As noted earlier, African countries are endowed with biomass and a large percentage of Africans generates fuel from biomass to meet their energy requirements. Unfortunately, not much attention is dedicated to the role of biomass in carbon emission in African countries. Considering this, our study examines the role of biomass in CO_2 emission in sixteen African countries from all the African regions, namely Northern, Western, Eastern, Southern, and Central Africa. This enables to understand the importance of biomass resources across the regions on the African continent, which will assist policy makers in making useful environmental and sustainable energy policy that can be embraced as regional policy.

Furthermore, studies with biomass focus are very few and some of these studies have neglected the role of vital variables such as trade openness and population growth in carbon emission. Given its technique, scale, and composition effects, trade openness plays a crucial contributing role to emissions (Farhani et al., 2014) and its inclusion in a carbon emission model will be useful. In addition, Fan et al. (2006) argue that the role of population growth in determining the quality of environment cannot be neglected while modelling environmental impacts. Hence, our study investigates carbon emission and biomass nexus by including trade openness and population growth in the model. The result of including these variables will be helpful to African policy makers in considering their role to address pollution while striving to attain sustainable development.

In terms of methodological approaches, this study considers the cross-sectional dependence (CSD, henceforth) issue unlike earlier studies. It is observed that failure to consider CSD may flaw studies, as results may be inconsistent, if the cross-sectional units are correlated. Therefore, we account for this issue and employ various second-generation panel estimation methods, such as Pesaran CADF and CIPS tests for unit roots, and Westerlund bootstrap ECM panel cointegration tests, which are robust to CSD. For the parameter estimates, we first apply mean group (MG), and pool MG (PMG) estimators that provide solutions to the issue of heterogeneity bias. Then, we employ second-generation estimators such as weighted FMOLS, and weighted DOLS, which deal with potential

autocorrelation and endogeneity problems, to validate the results obtained from PMG and MG estimators. Our findings from those estimators complement one another. Hence, they are reliable, robust, and free of inconsistences.

2. **Literature review**

Recently, the necessity to minimize climate change resulting from CO_2 emissions has made clean energy to receive an increasing attention on strategies for sustainable resource exploitation. The motivation for the increasing attention is not unconnected with the conclusion of some studies (as reviewed below) that the exploitation of biomass energy helps to dampen CO_2 emissions. In this paper, to conserve space, we decided to only review related studies that examined the impact of biomass energy usage, among other determinants, on carbon emissions. Furthermore, we review studies that investigated whether EKC proposition was valid for a country or panel of counties with a biomass focus. Finally, we review the previous results of causality among variables including biomass usage.

A survey of literature shows that a few studies included biomass energy use as other determinant of GH gas emissions and found that biomass energy helped to mitigate pollution of environment. These studies included Bilgili (2012), Bilgili et al. (2016), and Bilgili et al. (2017) for United States, Katircioglu (2015) for Turkey, Adewuyi and Awodumi (2017) for Burkina Faso, Gambia, and Mali, Sarkodie et al. (2019) for Australia, Carvalhoa et al. (2019) for Western Kenya, Danish and Ulucak (2020) for China, and Wang et al. (2020) for British Columbia. The findings of these studies indicate that policy makers efficiently adhere to biomass resource exploitation that society can keep at a steady level without hurting environment. However, Adewuyi and Awodumi (2017) found that biomass energy use degraded the quality of environment in other West African countries such as Nigeria, Senegal, Niger, and Togo.

With regards to EKC, some studies tested the validity of the hypothesis with a biomass focus and found that biomass energy usage helped to achieve inverted U-shaped relation of income with CO_2

emissions. For example, Dogan and Inglesi-Lotz (2017) use the EKC model to examine the influence of biomass energy usage on CO_2 emission for 22 biomass consuming countries. Findings suggest that biomass energy usage reduces environmental pollution and EKC holds for the countries. Similar conclusions were reached by studies such as Baležentis et al. (2019) for the EU countries, Shahbaz et al. (2017) for United States, Shahbaz et al. (2019) for MENA region and Middle East, and Danish and Wang (2019) for BRICS economies. The findings of these studies suggest that biomass energy decreases pollution and corroborates EKC proposition. However, studies such as Shahbaz et al. (2018) for G 7 countries, Solarin et al. (2018) for 80 countries, and Mahmood et al. (2019) for Pakistan do not find the relation of biomass energy use with CO_2 emission to be negatively significant. Concerning EKC, the findings of Shahbaz et al. (2018) and Solarin et al. (2018) support the proposition whereas those of Mahmood et al. (2019) do not support it.

In terms of causality tests, some studies specifically focus on biomass and economic growth to see the direction of causality between them. For instance, in the studies of US by Payne (2011) and Aslan (2016), biomass energy is found to Granger-cause economic growth without a feedback. Similar result confirming the growth hypothesis is found for Latin America by Bildirici (2013), G 7 economies by Bilgili and Ozturk (2015) and 51 countries of Sub-Sahara Africa by Ozturk and Bilgili (2015). However, Bildirici (2014) finds that biomass energy and GDP Granger-cause each other, thereby confirming a feedback hypothesis for the transition countries. Studies such as Bildirici and Ozaksoy (2013) and Bildirici (2013) report that the directions of causality between the variables are mixed for some EU countries and 10 emerging economies, respectively.

Recently, the focus of studies shifts to test the possibility of causalities among CO_2 emission, GDP, and biomass energy. For instance, Bilgili et al. (2017) and Shahbaz et al. (2017) perform the causality tests for United States and find that biomass energy and CO_2 emission Granger-cause each other, thereby confirming a feedback hypothesis. Similar result is found by Shahbaz et al. (2019) for MENA region and Middle East, and Mahmood et al. (2019) for Pakistan's study. Furthermore, some

of these studies (Bilgili et al., 2017; Mahmood et al., 2019; Shahbaz et al. 2017) confirm a feedback hypothesis between biomass and GDP. With regards to causality between GDP and CO_2 emission, Shahbaz et al. (2017) report that GDP has a unidirectional causality with CO_2 emission, whereas Shahbaz et al. (2019) find that the direction is either way.

Clearly, the literature shows that researchers are yet to reach an agreement on whether biomass energy improves or worsens CO_2 emissions. More so, the directions of causal link among CO_2 emission, GDP, and biomass energy remain ambiguous. All in all, the relation of biomass exploitation with CO_2 emissions has not been researched extensively unlike its relationship with GDP. Hence, more research is needed to provide useful and adequate suggestions to policy makers about biomass energy resource to achieve energy security and usage that can be kept at a steady level without damaging environment.

3. Model, data description, and estimation approaches

This study examines the impacts of fossil fuel, biomass energy use, income, trade, and population growth on carbon emissions using EKC model in African countries. It follows and augments earlier studies such as Bilgili (2012) and Katircioglu (2015) who model CO_2 emissions to depend on biomass energy and fossil fuel use. Specifically, our study augments this previous model by including GDP per capita and its squared term to further test whether EKC hypothesis exists in African countries. This leads us to investigate the following model 1.

$$\mathrm{lnC}_{it} = \gamma_0 + \gamma_1 \mathrm{lnB}_{it} + \gamma_2 \mathrm{lnF}_{it} + \gamma_3 \mathrm{lnG}_{it} + \gamma_4 \mathrm{lnGsq}_{it} + \mathrm{e}_{it} \qquad (1)$$

Some studies (Awad 2019; Danish and Wang 2019; Dogan and Seker, 2016; Ha Le et al., 2016; Ertugrul et al., 2016; Jebli et al., 2016; Managi et al., 2009) indicate that trade openness (TRO) has potential to predict the change in the level of CO_2 emissions. Hence, model 1 is modified by including TRO and this yields model 2 as follows:

$$\mathrm{lnC}_{it} = \gamma_0 + \gamma_1 \mathrm{lnB}_{it} + \gamma_2 \mathrm{lnF}_{it} + \gamma_3 \mathrm{lnTRO}_{it} + \gamma_4 \mathrm{lnG}_{it} + \gamma_5 \mathrm{lnGsq}_{it} + \mathrm{e}_{it} \qquad (2)$$

Furthermore, population is considered one of the important influential factors of environmental pollution and studies such as Fan et al. 2006, Hashmi and Alam, 2019 and Rauf et al. 2018 include it in a model using carbon emission as indicator of pollution. To account for the impact of population on CO_2 emissions, therefore, model 3 is specified as follows:

$$\mathrm{lnC}_{it} = \gamma_0 + \gamma_1 \mathrm{lnB}_{it} + \gamma_2 \mathrm{lnF}_{it} + \gamma_3 \mathrm{lnP}_{it} + \gamma_4 \mathrm{lnG}_{it} + \gamma_5 \mathrm{lnGsq}_{it} + \mathrm{e}_{it} \qquad (3)$$

In model (1-3), the measurement of CO_2 emission (lnC) is in metric tons per capita, biomass energy use (lnB) in metric tons, fossil fuel use (lnF) in metric tons. GDP per capita (lnG) and its squared term (lnGsq) are in constant 2010 US$, and e is an error term. In addition, trade openness (lnTRO) represents the sum of import and export as a percentage of GDP, and population growth (lnP) is measured as the percentage change in the number of people. Natural logarithm (ln) of variables enables interpretation of the estimates as elasticities of regressand (carbon emissions) with respect to regressors (B, F, TRO, P, G and Gsq). Table 1 further shows the description of the balanced panel dataset. Each country in the panel is represented by i across time t, and the parameter estimates are $\gamma_1 \; to \; \gamma_5$. Based on a priori and the literature, it is expected that the sign of $\gamma_1 < 0, and \; \gamma_2 > 0$. In model 2 and 3, it expected that $\gamma_3 < 0 \; and \; > 0,$ respectively. The EKC will be satisfied for African countries if $\gamma_4 > 0, and \; \gamma_5 < 0$ are achieved with statistical significance.

Table 1: Descriptive statistics

	lnC	lnB	lnF	lnTRO	lnP	lnG	lnGsq
Minimum	-4.117	15.698	11.264	1.843	-1.831	5.620	31.591
Maximum	2.300	20.144	19.232	4.920	1.487	9.122	83.229
Mean	-0.397	17.551	15.044	4.062	0.765	7.341	54.444
Std. Dev.	1.258	1.005	1.797	0.447	0.513	0.743	11.119
Observations	560	560	560	560	560	560	560

Concerning the data used, we collected data on carbon dioxide emissions, trade, population growth, and GDP per capita from World Bank's world development indicators and got data on biomass and fossil fuel energies use from materials flow database (http://www.materialflows.net). Because current data are not available for some sample countries, the study covers 1980 to 2014 period and due to limited data, some countries could not be included in the analysis. Despite this limitation, the study includes representative countries (Algeria, Egypt, Morocco, Tunisia, Kenya,

Mauritius, Zimbabwe, South Africa, Benin, Côte d'Ivoire, Ghana, Nigeria, Senegal, Togo, Cameroon, and Democratic republic of Congo) from all the five African regions in the 16 sample countries examined.

The estimation approach of this study follows steps. It first determines the existence of CSD in individual panel dataset using CD-test (Pesaran, 2004). Then, it determines the integration order of variables by considering the tests that can resolve the possible issue of CSD in heterogenous panels. Hence, it applies the Pesaran (2003) CADF test and Pesaran (2007) CIPS test, which are cross-sectionally augmented versions of ADF and IPS unit root tests, respectively. In the existence of CSD, both tests are commonly applied to examine unit roots because they can overcome the effect of CSD in heterogenous panels. In the case of CADF test, the effect is eliminated by augmenting ADF regressions with the cross-section means of the individual variables lagged at levels and first differences. The processes applied by the CIPS and CADF tests are similar, but the former employs the cross-sectional mean of the latter. In both tests, for the H_0: all series in a panel have unit roots whereas for the H_1: at least one series has no unit root (i.e., indicating stationarity).

If variables are found to be stationary after first differences, the subsequent step is to test for cointegration on panel dataset. To accomplish this, we use the Pedroni (1999, 2004), and Kao (1999) cointegration tests and Westerlund (2007) bootstrap error correction (EC) cointegration tests. Pedroni test yields seven distinct test statistics, which are based on the residuals obtained from the following regression, Eq. (4). Four of these test statistics are classified under within dimension and the remaining three statistics are under the between dimension with their associated probability values.

$$y_{it} = \varphi_i + \alpha_i T + \sum_{j=1}^{k} \beta_{ji} Z_{ji,t} + \varepsilon_{it} \qquad (4)$$

In Eq. (4), y_{it} is the regressand and $Z_{ji,t}$ are regressors, both of which should be an I(1) for individual panel i. The fixed effects, slope coefficient, and trend are φ_i , β_i, and T, respectively. The error term is denoted by ε_{it} and it is explicitly expressed as $\varepsilon_{it} = \gamma_i \varepsilon_{it-1} + \vartheta_{it}$. The residual's autoregressive

term is denoted by γ_i. For all the test statistics, the null hypothesis, $H_0 : \gamma_i = 1$ implies that y_{it} and $Z_{ji,t}$ have no long-run relationship for all i, and the alternative hypothesis, $H_1 : \gamma_i < 1$ suggests that y_{it} and $Z_{ji,t}$ are cointegrated for all panels. Also, the study employs panel cointegration test due to Kao (1999). The test is based on ADF statistics and does not provide for a time trend unlike Pedroni test.

For robustness check, we apply Westerlund (2007) bootstrap error correction model panel cointegration tests, which resolve the issue of CSD and heterogeneity. The test produces consistent and robust results and avoids the issue of common factor restriction. For the cointegrating relation between the regressand, $y_{i,t}$ and regressors, $Z_{i,t}$, the error correction (EC) model, Eq (5) is estimated.

$$\Delta y_{it} = \alpha_i + \varphi_{0i}(y_{i,t-1} - \beta_i Z_{i,t-1}) + \sum_{j=1}^{q_i} \varphi_{1ij}\, \Delta y_{i,t-j} + \sum_{j=0_i}^{q_i} \varphi_{2ij}\, \Delta Z_{i,t-j} + \varepsilon_{it} \quad (5)$$

where φ_{0i} measures the speed of adjustment and $y_{i,t-1} - \beta_i Z_{i,t-1} = 0$ gives the cointegration expression. If $\varphi_{0i} = 1$ it means there is no EC and, therefore, $y_{i,t}$ and $Z_{i,t}$ are not cointegrated. However, $\varphi_{0i} < 1$ suggests that EC exists and so $y_{i,t}$ and $Z_{i,t}$ are cointegrated. There are four tests in total and the outcomes of the test can be classified into two main parts. The first part is the group statistics (Gt), which is based on group mean and does not make use of information from the EC. The second part is the panel statistics (Pt), which is based on pooled panel knowledge. It pools information from cross-sectional EC term. The tests can produce both asymptotic and bootstrap critical values. Bootstrapping is particularly essential to address the CSD issue if detected. In this test, the H_0 implies that cointegration does not exist for at least one individual panel i for Gt and for all panels for Pt.

After establishing the cointegrating relation between variables, next is to compute the cointegration estimates. We achieve this by employing panel autoregressive distributed lag (ARDL) model. The ARDL method is appropriate for long panel as in the case of this study. The method

accommodates variables with mixed integrated order and due to the inclusion of lagged regressand and regressors in the model, it can address possible endogeneity problem (Pesaran et al., 1999). A specified unrestricted panel ARDL (p, q) model can be expressed as vector error correction model to give regression Eq. (6).

$$\Delta y_{it} = \varphi_{0i}\left(y_{i,t-1} - \beta_i Z_{i,t-1}\right) + \sum_{j=1}^{p-1} \varphi_{1ij}\, \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \varphi_{2ij}\, \Delta Z_{i,t-j} + v_i + \varepsilon_{it} \quad (6)$$

In Eq. (6), $y_{i,t-1} - \beta_i Z_{i,t-1} = 0$ is the long-run expression, y_i is the regressand (carbon emissions), φ_{1i} are the short-run dynamic estimates of lagged regressands. The lags of regressand and regressors are denoted by p and q, respectively. The term v_i denotes fixed effect and ε_{it} is the residual term.

Eq. (6) can be estimated using pool mean group (PMG), mean group (MG), and dynamic fixed effect (DFE) estimators. For PMG estimator (Pesaran *et al.,* 1999), the error correction term (φ_{0i}) and parameters of regressors (φ_{2i}) differ across the panels. However, the long run coefficients (β_i) are constant across the panels. The MG estimator (Pesaran and Smith, 1995) estimates the values of parameters for each panel in the whole cross-sections and computes the average of these estimated values. Both estimates, φ_{2i} and β_i are not restricted and can vary across the panels. For the DFE estimator, homogeneity of long-run estimates is imposed while the intercept can vary across countries like the PMG estimator. Unlike PMG, however, DFE restricts φ_{0i} and φ_{2i} not to vary across the panels. Lastly, Hausman (1978) test determines which of the estimators is more consistent and efficient. In other words, it determines whether the long-run estimates are truly homogenous or otherwise.

In the last step, the study checks to confirm the results obtained from the Panel ARDL estimators. To do this, it uses the weighted dynamic ordinary least squares (weighted DOLS) and weighted fully modified ordinary least squares (weighted FMOLS) to re-estimate the three models to further show the influences of regressors on CO_2 emission. The DOLS and FMOLS apply parametric and non-parametric approach, respectively. Unlike the latter, the former uses lags and leads of the regressors.

Consequently, the results obtained from these techniques are reliable as they correct for possible endogeneity in explanatory variables, and autocorrelation in the residual term. The weighted FMOLS estimator (Kao and Chiang, 2000) is given by Eq. (7) and the weighted DOLS regression (Mark and Sul, 1999) is given by Eq. (8). In the equations, $\hat{\beta}$ denotes the long-run estimate, C_{it} is the regressand (carbon emissions), Z_{it} are the regressors, $\hat{\lambda}_{12}$ is the serial correlation correction term, and the individual long-run variance estimates are $\widehat{w}_{1.2i}$.

$$\hat{\beta}_{FMOLS} = \left(\sum_{i=1}^{N}\left\{\sum_{t=1}^{T}(Z_{it} - \bar{Z}_i)^2\right\}\right)^{-1}\left(\sum_{i=1}^{N}\left\{\sum_{t=1}^{T}[\{Z_{it} - \bar{Z}_i\}\hat{C}_{it} - \hat{\lambda}_{12i}]\right\}\right) \qquad (7)$$

$$\hat{\beta}_{DOLS} = \left(\sum_{i=1}^{N}\widehat{w}_{1.2i}{}^{-1}\sum_{t=1}^{T} Z_{it}\, Z_{it}{}'\right)^{-1}\left(\sum_{i=1}^{N}\widehat{w}_{1.2i}{}^{-1}\sum_{t=1}^{T} Z_{it}\, C_{it}{}'\right) \qquad (8)$$

4. **Findings and discussions**

This study executes CD-test (Pesaran, 2004) to confirm the existence of CSD in individual panel dataset (i.e., to test H_0: cross-sectional independence exists). Table 2 presents the outcomes of the test and suggests rejecting the null hypothesis at the 1% significance level.

Table 2: Results of cross-sectional independence

	lnC	lnB	lnF	lnTRO	lnP	lnG	lnGsq
CD-test	5.105***	43.375***	39.395***	6.166***	28.501***	13.957***	14.184***
Prob. value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Prob. denotes probability.

As the results suggest that the variables in the panel have CSD, appropriate methods of estimation should be employed. In this regard, we apply bootstrap to our estimations to address this issue. More so, we employ weighted DOLS and the weighted FMOLS methods. These second-generation estimators can deal with possible autocorrelation and endogeneity problems that may occur (Dogan and Seker, 2016; Li et al., 2011).

Next, the study tests the integration properties of variables by implementing CADF and CIPS panel unit root test. Both tests are appropriate as they yield better results in the existence of CSD (Dogan and Inglesi-Lotz 2017; Pesaran, 2003, 2007). The test is conducted using a model that includes a time trend and the one without time trend. The outcomes provided in Table 3 indicate that all series are stationary, indicating that they are I(1). With these outcomes, the analyzed series satisfy the required conditions and thus we test the long-run relationships of the series.

Table 3: CADF and CIPS panel unit root test results

	CADF test				CIPS test			
	Without trend		Wit trend		Without trend		Wit trend	
Variable	(Level)	(Δ)	(Level)	(Δ)	(Level)	(Δ)	(Level)	(Δ)
lnC	-1.409	-3.231***	-2.447	-3.250***	-1.433	-5.815***	-2.927***	-5.899***
lnB	-2.007	-3.748***	-2.364	-3.871***	-2.875***	-5.863***	-3.089***	-6.038***
lnF	-1.919	-3.358***	-2.041	-3.389***	-2.638***	-5.549***	-2.812***	-5.653***
lnTRO	-2.011	-3.659***	-1.985	-3.901***	-1.833	-5.251***	-1.874	-5.364***
lnP	-1.601	-3.598***	-1.651	-3.743***	-1.631	-3.073***	-1.669	-3.352***
lnG	-1.371	-2.621***	-1.974	-3.326***	-1.393	-4.028***	-2.244	-4.069***
lnGsq	-1.434	-2.633***	-2.037	-3.308***	-1.455	-4.355***	-2.229	-4.422***

Note: Significant statistic with p-value ≤ 0.01 is indicated by ***.

4.3. Cointegration test results

The study conducts Kao test (Kao, 1999) to determine the cointegration of the series. Table 4 displays the output of the tests for the three models, which fails to support the null hypothesis. Hence, we conclude that a cointegrating relation exists among carbon emissions, biomass energy use, fossil fuel use, trade, population, GDP per capita and its quadratic term.

Table 4: Kao-Cointegration test results

	Model 1		Model 2		Model 3	
	Statistic	p-value	Statistic	p-value	Statistic	p-value
Augmented Dickey-Fuller	-7.193***	0.000	-7.320***	0.000	-7.374***	0.000

Note: Significant statistic with p-value ≤ 0.01 is indicated by ***.

In addition, we implement the Pedroni test (Pedroni, 1999, 2004) as it is appropriate for heterogeneous panels and the outputs of the tests are shown in Table 5. The outputs, based on the common and individual AR parameter options, suggest that the test statistics do not corroborate the null hypothesis of no long-run relation. Hence, we conclude that there exists cointegrating relation between carbon emissions and the regressors in all panels for the three models.

Table 5: Pedroni test for cointegration

	Model 1		Model 2		Model 3	
	Stat.	Weighted Stat.	Stat.	Weighted Stat.	Stat.	Weighted Stat.
Common AR parameter (within-dimension tests)						
Panel v-Stat.	-2.144	-1.951	-2.052	-1.935	-2.950	-2.643
Panel rho-Stat.	-1.634*	-2.494***	-0.594	-1.083	-0.251	-1.010
Panel PP-Stat.	-4.406***	-5.633***	-4.894***	-5.309***	-3.473***	-4.638***
Panel ADF-Stat.	-0.981	-3.698***	-5.973***	-5.770***	0.563	-2.489***
Individual AR parameter (between-dimension tests)						
Group rho-Stat.	-0.553		0.493		0.901	
Group PP-Stat.	-4.682***		-4.749***		-3.971***	
Group ADF-Stat.	-3.854***		-5.061***		-4.447***	

Note: Stat. denotes Statistic. Significant statistics with p-value ≤ 0.01 and ≤ 0.1 are indicated by *** and *, respectively.

The Kao, and Pedroni tests of cointegrating relation employed are regarded as first-generation tests due to their assumption that cross-sectional independence exists. This assumption might bias the cointegration test results. Thus, we conduct a second-generation test of cointegrating relation among the series by applying the Westerlund (2007) bootstrap ECM panel cointegration tests to verify whether the first-generation tests of cointegration are valid. The bootstrap ECM panel cointegration tests address the concerns over CSD as well as the issue of heterogeneity across the panel while determining the cointegrating relation between the series. For the three models, the outputs of the tests presented in Table 6 confirm that there exists cointegrating relation between the variables in support of the alternative hypothesis.

Table 6. Westerlund bootstrap ECM panel cointegration tests

	Model 1			Model 2			Model 3		
	Value	Z-value	Robust p-value	Value	Z-value	Robust p-value	Value	Z-value	Robust p-value
Gt	-3.332***	-3.713	0.000	-3.590***	-3.959	0.003	-3.591***	-3.965	0.000
Ga	-13.830***	-0.456	0.000	-14.204***	0.374	0.005	-13.766***	0.587	0.005
Pt	-12.524**	-3.628	0.028	-14.671***	-4.791	0.003	-13.094**	-3.333	0.033
Pa	-11.482*	-1.148	0.080	-12.728*	-0.678	0.073	-11.156	0.076	0.185

Note: Significant statistics with p-value ≤ 0.01, ≤ 0.05, and ≤ 0.1 are indicated by ***, **, and *, respectively. Bootstrap achieved using 400 replications for all the models.

4.5. Results of cointegration estimates

We estimate the long run influences of regressors on $C0_2$ emissions by applying PMG, MG and DFE estimators. These estimators provide solutions to heterogeneity bias. The MG estimator is appropriate for models with heterogeneous influences (Pesaran and Smith, 1995) whereas PMG and

DFE estimators are suitable for models with homogeneous influences (Pesaran and Shin, 1999). Besides, the panel ARDL models are suitable for use even if the series possess mixed order of integration, such as I(1), and I(0) (Pesaran and Shin, 1999). Table 7 presents the results of estimations in which the Hausman test suggests that the long-run slope coefficients are indeed homogeneous and consequently PMG is an efficient estimator compared to MG. Thus, we focus on interpreting the outputs from PMG and DFE estimators. Also, the coefficients of adjustment as indicated by error correction terms (ECT) are found to be negatively significant at 1% for all the estimators in all the models.

The outcomes from PMG estimator show that all the regressors play crucial role in affecting the African environments in all the models. Specifically, we find that GDP per capita (lnG) has positive relation with $C0_2$ emissions. This relationship is significant at 1% in all the models and suggests that a rise in income of African countries increases $C0_2$ emissions, thereby worsening the quality of African countries' environment. However, the initial positive effect of income on emissions continues up to a point where it turns negative as indicated by the significant negative coefficient of quadratic income (lnGsq). This suggests an inverted U-shaped relation of income with $C0_2$ emission in African society where biomass energy is in use. The inverted U-shaped association observed for African countries can be linked to structural change in income and an improved technology, which lead to early worsening of environment. But the subsequent reduction in environmental degradation along with increasing income can be ascribed to various environmental control measures and policies applied to lessen pollution in order to meet societal demand for better environment. Related studies with results supporting EKC in a model including biomass energy use include Dogan and Inglesi-Lotz (2017), Shahbaz et al. (2018), and Danish and Wang (2019).

Table 7. Estimated coefficients from long-run estimators

	Model 1			Model 2			Model 3		
	Coefficients			Coefficients			Coefficients		
Variable	PMG	MG	DFE	PMG	MG	DFE	PMG	MG	DFE
lnG	4.411***	3.995	2.351***	4.662***	10.895	2.928***	4.404***	2.542	1.888***
lnGsq	-0.265***	-0.193	-0.112**	-0.279***	-0.697	-0.144***	-0.261***	0.036	-0.079
lnF	0.490***	0.564**	0.471***	0.478***	0.522***	0.445***	0.450***	0.596***	0.490***

lnB	-0.169***	-0.534*	-0.451***	-0.154**	-0.371	-0.379***	-0.113**	-0.611**	-0.442***
lnTRO	-	-	-	-0.063**	-0.097	-0.174***	-	-	-
lnP	-	-	-	-	-	-	0.044*	-1.464	0.117**
ECT	-0.365***	-0.611***	-0.382***	-0.381***	-0.684***	-0.393***	-0.427***	-0.712***	-0.394***
Hausman test	0.375			0.904			0.635		

Notes: Significant statistics with p-value ≤ 0.01, ≤ 0.05, and ≤ 0.1 are indicated by ***, **, and *, respectively.

We also find that fossil fuel energy use (lnF) affects $C0_2$ emissions positively, and the effect is significant at 1%. This implies that a 10% increase in fossil fuel energy use results in around 4.9% increase in $C0_2$ emissions in the model without trade and population as regressors. The effect of fossil fuel slightly decreases to 4.8% when only trade is included in model 2, and to 4.5% when only population is included in model 3. The result is as expected since fossil fuel energy constitutes most important source of $C0_2$ emissions (Bilgili, 2012; Katircioglu, 2015).

Due to the need to meet societal demands for better environmental quality and because African countries are endowed with alternative energy source such as biomass, which has less carbon emissions, we examine the potential of biomass energy use to lessen the deterioration of environmental quality. Interestingly, results from the PMG estimator indicate that biomass energy use (lnB) has a dampening effect on $C0_2$ emissions in those countries. Precisely, the influence of biomass energy use on $C0_2$ emissions is negatively significant in the three models. That is, as biomass energy usage increases by 10% $C0_2$ emissions reduces by around 1.7%, 1.5%. and 1.1% in the three models respectively. As found in this study, the utilization of biomass energy with its dampening effect on $C0_2$ emissions lends support to similar results found by Bilgili (2012) for USA, Katircioglu (2015) for Turkey, Dogan and Inglesi-Lotz (2017) for 22 biomass consuming countries, Adewuyi and Awodumi (2017) for Burkina Faso, Gambia, and Mali, Danish and Wang (2019) for BRICS countries, Sarkodie et al. (2019) for Australia, Danish and Ulucak (2020) for China.

While fossil fuel energy use is found to increase $C0_2$ emissions, biomass energy use decreases the emissions to support the current global switch to a decarbonized economy. This means that African society can quickly record progress in achieving green economy if substantial preference is given to biomass energy use. Undoubtably, this is possible because the countries are very rich in biomass

energy sources varying from forestry and agricultural remains, wood made from agro-industrial plantations to non-wood generated from plant stems, and crop remains. Given these resources, biomass as source of renewable energy could serve as substitute to fossil fuel, a non-renewable energy source if the endowed biomass resources are employed efficiently.

From the results of model 2 in Table 7, trade openness exerts significant negative impact on carbon emissions, suggesting that an increase in trade openness by 10% leads carbon emissions to decrease by 0.6%. This result corroborates that of Awad (2019), Dogan, and Seker (2016), Jebli et al. (2016), and Al-Mulali et al. (2015) but contradicts that of Danish and Wang (2019). The improvement in the quality of environment resulting from increased trade may be due to technique effect from the import and use of technologies which are friendly to environment. It may also be due to composition effect exerted by increased trade in which the sectors producing goods a country has comparative advantage are not energy intensive and consequently, a reduction in pollution.

It is noted that population is among the important factors a path-breaking approach will include in an environmental model (Fan et al. 2006). The result of including population in model 3 shows significant positive coefficient, which suggests that a 10% growth in population results in a 0.4% increase in $C0_2$ emissions. This supports the findings of Fan et al. (2006), Hashmi and Alam, (2019) and Rauf et al. (2018) in which population is found to contribute to increased carbon emissions.

Turning to the outputs obtained from DFE estimator, Table 7 show the significant impacts of all the regressors, except the quadratic income in model 3, on $C0_2$ emissions with expected signs. In this respect, the DFE results are somewhat similar to those reported for PMG estimator.

Table 8. Robustness test results from Weighted FMOLS and DOLS

	Model 1		Model 2		Model 3	
	Coefficients		Coefficients		Coefficients	
Variable	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS
lnG	2.371***	3.642***	2.573***	3.787***	1.912***	3.117***
lnGsq	-0.137***	-0.195***	-0.143***	-0.198***	-0.091***	-0.156***
lnF	0.414***	0.412***	0.406***	0.395***	0.475***	0.429***
lnB	-0.446***	-0.286***	-0.419***	-0.268***	-0.461***	-0.294***
lnTRO	-	-	-0.063***	-0.120***	-	-
lnP	-	-	-	-	0.117***	0.179***
R^2	0.971	0.987	0.973	0.991	0.976	0.992

Notes: Significant statistic with p-value ≤ 0.01 is indicated by ***.

Furthermore, we employ second-generation estimation methods like weighted FMOLS, and weighted DOLS to estimate the same model. These estimators also address possible autocorrelation and endogeneity problems in the error terms and regressors, respectively. This enables to obtain robust and reliable estimates of parameters. The results of using weighted FMOLS, and weighted DOLS are presented in Table 8. The outputs obtained from these estimators indicate that all the signs of regressors are as expected and they are significant at 1% level thereby supporting the outputs obtained from PMG and DFE estimators in Table 7. This implies that the long-run estimates reported for panel ARDL estimators are valid and reliable to make inferences.

5. Concluding remarks and policy implications

This paper investigates the influences of biomass energy use, fossil fuel, income, trade, and population growth on $C0_2$ emission and tests whether there exists EKC in African countries. To achieve the estimates of the parameters, the study employs PMG, MG, and DFE estimators which resolve the issue of heterogeneity bias. In addition, we employ weighted FMOLS, and weighted DOLS to validate the robustness of PMG outputs. The results obtained from each of these estimators complement one another and both suggest that the relation of population growth and fossil fuel use with CO_2 emission is positively significant. Conversely, we find that trade openness and biomass energy use exert significant negative impact on carbon emission. That is, increased trade and biomass energy consumption have a dampening effect on emissions. More so, these results validate EKC hypothesis for those African countries. Based on various econometric methods employed in which the verdict of one approach confirms the verdict of other in the same category, one can conclude that the reported findings are robust, consistent, and plausible to make inferences.

The finding of this study suggests that the effect of population increase harms the African environment. This implies that population reduction is imperative to lessen carbon emissions in those countries and the optimal strategy to achieve this is to resort to population growth control. However,

opening trade is found to improve the quality of environment in African countries by reducing the demand for energy use. This is in the right direction and policy makers should ensure consistency in the policies and regulations guiding the opening trade in those countries.

Furthermore, our findings indicate the use of energy sourced from biomass helped to mitigate emissions in African countries. The results will be useful to motivate the non-users of biomass to appreciate its dampening effect on emissions. Thus, it is recommended that African countries encourage the consumption of biomass energy by substituting it for fossil fuel energy since the countries are endowed with various sources of biomass. To ensure this, the policy making authorities need to raise more awareness about the benefits of shifting to the use of biomass energy. In addition, they can make national policies that encourage increase share of biomass in the national energy mix as this will to a large extent minimize the CO_2 in the air and prevent climate change.

Naturally, the panel of African countries is blessed with forest resources from which biomass energy is majorly generated. Forests play a bigger role in reducing emissions as they currently remove around 25 percent of CO_2 (National Geographic, 2018). Hence, national policy makers should formulate a policy that encourages reforestation and improvement of forest management to ensure the achievement of SDG 15. The implementation of this policy could help to remove from the air sizable percentage of CO_2 needed for reduction by the year 2030. Also, it is essential to protect and increase tropical forests due to their crucial roles among which is the cooling of the air. Thus, appropriate policy which ensures protection of existing forests will be desirable to prevent dangerous climate change.

Declarations

*Author Contributions

All the authors have significantly contributed to carry out this research. Dr Raji Jimoh collected the data, performed econometric analysis, and wrote the result and discussion section. Likewise, Dr. Rana Muhammad Adeel-Farooq completed the Introduction and literature review sections.

Similarly, Dr. Ghulam Muhammad Qamri wrote the conclusion, done data analysis and reviewed the entire manuscript.

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Consent to Participate

Not Applicable

***Ethical Approval**

All the ethical codes are followed while conducting this research. This research has not been submitted to any other journal except this journal. All the data employed in this research is obtained through reliable sources and true. The analysis has been done in a fair manner.

***Consent to Publish**

The publisher hereby is given full consent to publish this research if accepted.

*Availability of data and materials

Data and all the other materials will be shared if required.

References

Adeel-Farooq, R.M., Raji, J.O., Adeleye, B.N., 2021. Economic growth and methane emission: testing the EKC hypothesis in ASEAN economies. Management of Environmental Quality: An International Journal, 32(2), 277-289.

Adewuyi, A.O., Awodumi, O.B., 2017. Biomass energy consumption, economic growth and carbon emissions: fresh evidence from West Africa using a simultaneous equation model. Energy 119, 453-471.

Al-Mulali U, Ozturk I, Lean H H. 2015. The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe. Nat Hazards, 79(1):621–44.

Al-Mulali, U., Weng-Wai, C., Sheau-Ting, L., Mohammed, A.H., 2015. Investigating the environmental Kuznets curve (EKC) hypothesis by utilizing the ecological footprint as an indicator of environmental degradation. Ecol. Indicat. 48, 315-323.

Asıcı, A.A., Acar, S., 2016. Does income growth relocate ecological footprint? Ecol. Indicat. 61, 707-714.

Aslan, A. 2016. The causal relationship between biomass energy use and economic growth in the United States. Renewable and Sustainable Energy reviews, 57, 362-366.

Awad, A. 2019. Does economic integration damage or benefit the environment? Africa's Experience. Energy Policy 132 (2019) 991–999

Baležentis, T., Streimikiene, D., Zhang, T., Liobikiene, G., 2019. The role of bioenergy in greenhouse
gas emission reduction in EU countries: an environmental Kuznets Curve modelling. Resour. Consev . Recycl. 142, 225–231.

Beckerman, W., 1992. Economic growth and the environment: whose growth? Whose environment? World Dev. 20, 481–496.

Bildirici ME., 2013. Economic growth and biomass energy. Biomass Bioenergy, 50, 19–24.

Bildirici ME., 2014. Relationship between biomass energy and economic growth in transition countries: panel ARDL approach. GCB Bioenergy, 6, 717–26.

Bildirici, M.E., Ozaksoy, F., 2013. The relationship between economic growth and biomass energy consumption in some European countries. Journal of Renewable and Sustainable Energy, 5(2), 23-41.

Bildirici, M.E, Özaksoy, F., 2018. An analysis of biomass consumption and economic growth in transition countries. Econ. Res. Istraživanja, 31, 386–405.

Bilgili F., 2012. The impact of biomass consumption on CO2 emissions: cointegration analyses with regime shifts. Renew Sust Energ Rev 16(7), 5349–5354.

Bilgili, F., Koçak, E., Bulut, Ü., Kuşkaya, S., 2017. Can biomass energy be an efficient policy tool for sustainable development? Renew. Sustain. Energy Rev. 71, 830–845.

Bilgili F, Ozturk I., 2015. Biomass energy and economic growth nexus in G7 countries: evidence from dynamic panel data. Renew Sustain Energy Rev. 49, 132–8.

Bilgili, F., Öztürk, İ., Koçak, E., Bulut, Ü., Pamuk, Y., Muğaloğlu, E., Bağlıtaş, H.H., 2016. The influence of biomass energy consumption on CO2 emissions: a wavelet coherence approach. Environ. Sci. Pollut. Res. 23, 19043–19061.

BP (2019). BP Statistical Review of World Energy 2019: an unsustainable path. https://www.bp.com /en/global/corporate/news-and-insights/press-releases/bp-statistical-review-of-world-energy-2019.ht ml.

Carvalhoa, R.L., Lindgrena, R., García-Lópeza, N., Nyambaned, A., Nyberge, G., Diaz-Chavezd, R., Bomana, C., 2019. Household air pollution mitigation with integrated biomass/cookstove strategies in Western Kenya. Energy Policy 131, 168–186.

Danish, Ulucak R., 2020. Linking biomass energy and CO2 emissions in China using dynamic Autoregressive-Distributed Lag simulations, Journal of Cleaner Production.

Danish and Wang, Z., 2019. Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries, Science of the Total Environment, 670, 1075–1083.
Darda, S., Papalas, T., Zabaniotou, A., 2019. Biofuels journey in Europe: currently the way to low carbon economy sustainability is still a challenge. J. Clean. Prod. 208, 575-588.

Dogan, E. and Seker, F., 2016. The influence of real output, renewable and non-renewable energy, trade, and financial development on carbon emissions in the top renewable energy countries. Renewable and Sustainable Energy Reviews, 60, 1074–1085

Dogan, E. and Inglesi-Lotz, R., 2017. Analyzing the effects of real income and biomass energy consumption on carbon dioxide (CO2) emissions: Empirical evidence from the panel of biomass consuming countries. 138, 721-727.

Ertugrul, H., Cetin, M., Sekerc, F., Dogan, E., 2016. The impact of trade openness on global carbon dioxide emissions: evidence from the top ten emitters among developing countries. Ecol. Indicat. 67, 543–555.

Fan, Y., Liu, L.-C., Wu, G., Wei, Y.-M., 2006. Analyzing impact factors of CO2 emissions using the STIRPAT model. Environ. Impact Assess. Rev. 26, 377–395. https://doi.org/10.1016/j.eiar.2005.11 .007.

Farhani, S., Chaibi, A., Rault C., 2014. CO2 emissions, output, energy consumption, and trade in Tunisia. Econ Modell 2014; 38:426–34.

Granger, C. W., 1969. Investigating causal relations by econometric models and cross-spectral methods. Econometrica, 37(3), 424-438.

Grossman, G.M., Krueger, A.B., 1991. Environmental impacts of a North American Free Trade Agreement. National Bureau of Economic Research, Cambridge MA. Working Paper Series. No. 3914, 1–57.

Grossman, G.M., Krueger, A.B., 1995. Economic growth and the environment. Q. J. Econ. 110, 353–377.

Ha Le, T., YChang, Y., Park, D., 2016. Trade openness and environmental quality: international evidence. Energy Policy 92, 45–55.

Hashmi, R., Alam, K., 2019. Dynamic relationship among environmental regulation, innovation, CO2 emissions, population, and economic growth in OECD countries: a panel investigation. J. Clean. Prod. 231, 1100–1109. https://doi.org/10.1016/j.jclepro.2019.05.325.

Hausman, J. A 1978). Specification tests in econometrics. Econometrica 46, 1251–1271

Iiyama M, Neufeldt H, Dobie P, Njenga M, Ndegwa G, Jamnadass R., 2014. The potential of agroforestry in the provision of sustainable woodfuel in sub-Saharan Africa. Curr Opin Environ Sustain 6, 138–147.

Jebli, M.B., Youssef, S.B., Ozturk, I., 2016. Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD countries. Ecol. Indic. 60, 824–831.

IPCC 2018. Global Warming of 1.5°C. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_Low_Res.pdf

Kao, C., 1999. Spurious regression and residual-based tests for cointegration in panel data. Journal of Econometrics, 90(1), 1–44.

Kao, C and Chiang M-H., 2000. On the Estimation and Inference of a Cointegrated Regression in Panel Data, in Baltagi, B. H. et al. eds., Nonstationary Panels, Panel Cointegration and Dynamic Panels, 15, Amsterdam: Elsevier, 179–222.

Katircioglu, S.T., 2015. The impact of biomass consumption on CO2 emissions. An empirical investigation from Turkey. Int. J. Clim. Chang. Strateg. Manag. Artic. Inf. 7, 348–358.

Li F, Dong S, Li X, Liang Q, Yang W., 2011. Energy consumption-economic growth relationship and carbon dioxide emissions in China. Energy Policy, 39, 568–74.

Liu, W., Xu, J., Xie, X., Yan, Y., Zhou, X., Peng, C. 2020. A new integrated framework to estimate the climate change impacts of biomass utilization for biofuel in life cycle assessment Journal of Cleaner Production 267, 122061.

Lv, Z., Xu, T., 2018. Trade openness, urbanization and CO2 emissions: dynamic panel data analysis of middle-income countries. J. Int. Trade Econ. Dev. 1–14.

Managi, S., Hibiki, A., Tsurumi, T., 2009. Does trade openness improve environmental quality? J. Environ. Econ. Manag. 58 (3), 346–363.

Mark, N.C. and Sul, D., 1999. A Computationally Simple Cointegration Vector Estimator for Panel Data, Ohio State University manuscript.

Mahmood, N., Wang, Z., Yasmin, N., Manzoor, W., Rahman, A., 2019. How to bend down the environmental Kuznets curve: the significance of biomass energy. Environ. Sci. Pollut. Res. 26.

National Geographic 2018. Climate change impacts worse than expected, global report warns. https://www.nationalgeographic.com/environment/2018/10/ipcc-report-climate-change-impacts-forests-emissions

Owusu, P.A., Asumadu-Sarkodie, S., 2016. A review of renewable energy sources, sustainability issues and climate change mitigation. Cogent Eng. 3, 1–14.

Ozturk, I., Al-Mulali, U., Saboori, B., 2016. Investigating the environmental Kuznets curve hypothesis: the role of tourism and ecological footprint. Environ. Sci. Pollut. Control Ser. 23 (2), 1916-1928.

Ozturk I, Bilgili F., 2015. Economic growth and biomass consumption nexus: dynamic panel analysis for sub-Sahara African countries. Appl Energy 137, 110–116.

Panayotou, T., 1993. Empirical tests and policy analysis of environmental degradation at different stages of economic development. Working Paper WP238, Technology and Employment Programme, International Labour Office, Geneva.

Payne, J.E., 2011. On biomass energy consumption and real output in the US. Energy Sour Part B: Econ Plan Policy, 6, 47–52.

Pedroni, P. 1999. Critical values for cointegration tests in heterogeneous panels with multiple regressors. Oxford Bulletin of Economics and Statistics 61, 653–670.

Pedroni, P. 2004. Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Econometric Theory, 20, 597–625.

Pesaran, H. M., 2003. A Simple Panel Unit Root Test in the Presence of Cross Section Dependence, Cambridge Working Papers in Economics 0346, Faculty of Economics (DAE), University of Cambridge.

Pesaran M.H., 2004. General diagnostic tests for cross-section dependence in panels. Faculty of Eco, 1–39.

Pesaran, M. H., 2007. A simple panel unit root test in the presence of cross-section dependence. Journal of Applied Econometrics 22(2), 265–312.

Pesaran, M. H. 2015. Testing Weak Cross-Sectional Dependence in Large Panels. Econometric Reviews 34(610), 1089-1117.

Pesaran, M.H., Shin, Y.C. and Smith, R.P., 1999. Pooled mean group estimation if dynamic heterogeneous panels, Journal of the American Statistical Association, 94(446), 621-634.

Pesaran, M.H. and Smith, R.P., 1995. Estimating long-run relationships from dynamic heterogeneous panels, Journal of Econometrics, 68(1), 79-113.

Rauf, A., Liu, X., Amin, W., Ozturk, I., Rehman, O.U., Hafeez, M. 2018. Testing EKC hypothesis with energy and sustainable development challenges: a fresh evidence from belt and road initiative economies. Environmental Science and Pollution Research, 25, 32066-32080. https://doi.org/10.1007/s11356-018-3052-5

Saboori, B., Sulaiman, J. and Mohd, S., 2012. Economic growth and CO2 emissions in Malaysia: a cointegration analysis of the Environmental Kuznets Curve, Energy Policy, 51, 184-191.

Sarkodie, S.A., Strezov, V., Weldekidan, H., Asamoah, E.F., Owusu, P.A., Doyi, I.N.Y., 2019. Environmental sustainability assessment using dynamic Autoregressive-Distributed Lag simulations

-Nexus between greenhouse gas emissions, biomass energy, food and economic growth. Sci. Total Environ. 668, 318–332.

Selden, T. M., and Song, D., 1994. Environmental quality and development: Is there a Kuznets curve for air pollution? Journal of Environmental Economics and Management, 27, 147–162.

Schuck, S., 2006. Biomass as an energy source. International Journal of Environmental Studies, 63(6), 823–835.

Shafik, N., 1994. Economic development and environmental quality: An econometric analysis. Oxford Economic Papers, 46, 757–773.

Shafik, N., Bandyopadhyay, S., 1992. Economic Growth and Environmental Quality: Time Series and Cross-country Evidence. Background Paper for the World Development Report 1992, The World Bank, Washington, DC.

Shahbaz, M., Balsalobre, D., Shahzad, S.J.H., 2018. The influencing factors of CO2 emissions and the role of biomass energy consumption: statistical experience from G-7 countries. Environ. Model. Assess.

Shahbaz, M., Balsalobre-Lorente, D., Sinha, A., 2019. Foreign direct InvestmenteCO2 emissions nexus in Middle East and North African countries: Importance of biomass energy consumption. Journal of Cleaner Production 217, 603-614.

Shahbaz, M., Sharma, R., Sinha, A., Jiao, Z., 2021. Analyzing nonlinear impact of economic growth drivers on CO2 emissions: Designing an SDG framework for India. Energy Policy 148, 111965.

Shahbaz, M., Solarin, S.A., Hammoudeh, S., Shahzad, S.J.H., 2017. Bounds testing approach to analyzing the environment Kuznets curve hypothesis with structural beaks: the role of biomass energy consumption in the United States. Energy Econ. 68, 548–565.

Solarin, S.A., Al-Mulali, U., Gan, G.G.G., Shahbaz, M., 2018. The impact of biomass energy consumption on pollution: evidence from 80 developed and developing countries. Environ. Sci. Pollut. Res., 1–17.

Stern, D.I., Common, M.S., Barbier, E.B., 1996. Economic growth and environmental degradation: the environmental Kuznets curve and sustainable development. World Dev. 24, 1151–1160.

UNDP 2009. The energy access in situation in developing countries: a review focusing on the least developed countries and sub-Saharan Africa. UNDP, New York, p 2009

Wang, H., Zhang, S., Bi, X., Clift, R., 2020. Greenhouse gas emission reduction potential and cost of bioenergy in British Columbia, Canada. Energy Policy, 138, 111285.

Westerlund, J. 2007. Testing for Error Correction in Panel Data. Oxford Bulletin of Economics and Statistics 69(6): 709-748.

Yahaya, N.S., Mohd-Jali, M.R., Raji, J.O., 2020. The role of financial development and corruption in environmental degradation of Sub-Saharan African countries. Management of Environmental Quality: An International Journal, 31(4), 895-913.